made with kites and could not have been obtained in the calm air which occurs with inversions. Thus it appears that the results obtained by Doctor Meisinger for the two stations in question can not be accepted without further investigation.

If these data be rejected then the variations in Meisinger's coefficient a are so insignificant that the characteristic features of his charts disappear. This would in fact be an advantage; for a general formula applicable to all parts of the region would be preferable to one suitable only for use within narrow limits.

I trust that Doctor Meisinger will find an opportunity to reexamine the results which have been called in question and that he will let it be known how the anomalous figures are to be explained.

DISCUSSION

I am very greatly indebted to Doctor Whipple for the consideration and constructive criticism he has given my article. Only the pressure of work relative to field activities of the Weather Bureau prevents me from attacking the problem from Doctor Whipple's point of view at once. This reexamination of the data which he has suggested must necessarily be deferred for several months.

The very gratifying thing about the criticism is that it points the way to a more equable distribution of the constant a over the country. On page 446, second and third paragraphs of my paper now under discussion,[1] the reader will observe that no effort was made to give the tone of finality to the explanation of the empirically determined geographical distribution of this constant. It was confessedly anomalous and Doctor Whipple's suggestions may help to ferret out the reason for the anomaly. While it is true that two of my values exceed that given by Doctor Whipple as a maximum, I may say that I have the utmost confidence in the arithmetical calculations by means of which those values were derived. It is, therefore, a matter of the keenest interest to me to approach the same body of data from another point of view.—*C. Le Roy Meisinger.*

282.271

PROBLEMS OF THE LOWER COLORADO RIVER

By JAMES H. GORDON

[Weather Bureau, Yuma, Ariz., December, 1923]

The lower Colorado River is roughly defined as that portion of the stream below the 500 foot contour. It embraces some 350 miles of channel extending from the southeastern corner of Nevada to the Gulf of California. Along the lower third of this distance the river flows through its delta. It is in this delta country that most development has taken place and here, naturally, most of our problems have arisen.

The Colorado River as it comes to us out of the hills is a quiet and naturally law-abiding stream 10 months of the year. For the other two months it ceases to be quiet and is law abiding only because of strong levees that hold it in restraint. During this period, the time of the spring floods, it becomes a powerful, turbulent river. It is then a threat against every bit of development along its banks.

There is but one important tributary entering the lower Colorado. This is the Gila River. It is a typical southwestern stream flowing "sandy side up" most of the time but capable of staging floods of very serioue proportions occasionally. Fortunately, these floods come during the winter months and within the memory of man, at least, have never coincided with high water in the Colorado. Both the Gila and Colorado are hard working streams. Joining just above Yuma they bring down in an average year some 6,000,000 carloads of silt and sand, a hundred thousand acre-feet of soil, for their delta building.

Having this introduction to the river itself we may turn to its problems. One of them is of especial interest not only because of its importance to the delta country but because it is unique among the river problems of the United States if not of the world. The problem is best understood if traced back to its beginning. The beginning was a good many thousand years ago, about the time the Colorado River emerged from the hills to the north and joined forces with the Gila at Yuma. At that time the Gulf of California extended some 150 miles north of its present limits with an eastward extension to the neighborhood of Yuma. Into this eastern arm of the Gulf the Colorado and Gila poured their muddy waters. (See fig. 1.)

In the long period of time which followed the rivers brought down many hundreds of cubic miles of rock and sand and mud, the scourings of the Grand Canyon and the ten thousand lesser gorges, and the wash-off from 240,000 square miles of territory. The delta grew and filled in the eastern arm of the Gulf. The Colorado and Gila became one river and pushed the delta head farther and farther out until it reached clear to the western shore; built it up until it formed a dam cutting off the northern section of the Gulf from the ocean. (See fig. 2.) This, too, was a good many thousand years ago and the river has kept on building. To-day the dam, above sea level, is nearly a hundred miles wide. The course of the Colorado River lies between the twin crests of this delta cone more than 30 feet above the sea. It turns to the left toward the Gulf, 50 miles away. To the right lies the old sea bed, the Salton Basin, its lowest point more than 300 feet below the river level and but 70 miles away. (See fig. 3.)

One must wonder that the river takes the sluggish way to the Gulf instead of a grade nearly ten times as steep into Salton Basin. It is true that now there are levees to prevent its turning north, but long before the levees were built the river was taking the sluggish course rather than the steep one.

There is little question that the Colorado River has flowed into the Salton Basin a number of times during the last 10,000 years, turned from the Gulf to the old sea bed. Such a change stirs one's imagination. There would be the gradual preparation, the south side of the river building up a little higher each year with an added layer of silt, the north bank cut increasingly by overflow at flood time; then finally at some high water a cut would reach back clear through the north bank to the main channel, the river would feel the urge of the steeper grade and turn roaring onto the desert. It would be something to see, this turning of a mighty river into the dry, barren old basin, the growth of a sea in the desert, the blotting out of a million acres of sand. In 30 or 40 years the basin would be full to the brim, probably with an outlet to the Gulf to carry off the high waters of flood time. But the grade would be gone. Instead of roaring out onto the desert the river would flow sluggishly into a quiet sea to drop its load and start in again on the old business of delta building. With the passing years the river would shift back and forth, east and west, as a

[1] MO. WEATHER REV., September, 1923, 51: 437-448.

delta cone became a dam and the river sought an easier channel. It is hard to say how long this would take, the building up of the north bank to the danger point,

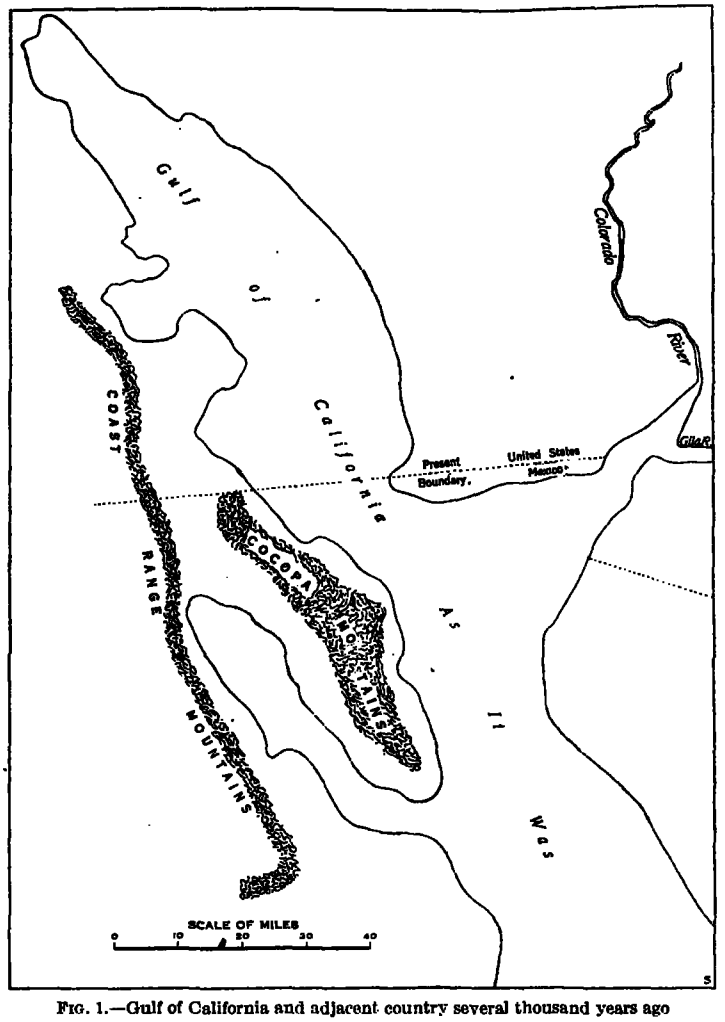

FIG. 1.—Gulf of California and adjacent country several thousand years ago

probably three or four hundred years at least. Eventually, inevitably, at some high water a break would come in the south bank, for any grade is better than none, and the river would turn again toward the Gulf, to start the damming process all over again.

Something less than a thousand years ago, geologists tell us, the last shift into the south took place. For many years the Colorado River had flowed into the Salton Basin. Indian villages lay along its shores, the people living by fishing and growing corn on the overflow land following each high water. Then, the building up of the north bank being sufficient, the river turned south and the desert crept back as the sea shrunk away to nothingness. It was a great catastrophe to the fisher people. They were driven away to find other homes. Traces of the old villages still remain.

For nearly a thousand years the Salton Basin lay empty, a sun-baked, barren desert (fig. 4). So white men found it and hated its glaring desolation. Some 70 years ago an Army engineer proposed to re-create the sea, to turn the Colorado River into the Salton Basin again. His plans came to nothing but other men came after him with other plans. It was 50 years before the plans bore fruit. Twenty-two years ago men turned the waters of the Colorado River back into the Salton Basin, and a sea appeared in the desert. But this was not like the sea which had evaporated a thousand years before. It was a sea of green, miles and miles of alfalfa fields, thousands of acres of cotton and grain, great acreas of melons, vineyards, truck farms, and fruits. Cities grew up in the midst of it. The new sea in the desert supports a population probably a hundred times as great as the Indian villages could boast. More than three-quarters of a million acres of land have come under cultivation.

Here then is our problem. The Colorado River flowing along the crest of a ridge turns to the left to follow a sluggish way to the Gulf. To the right is the Salton Basin, its lowest point but a little farther from the river than the Gulf and offering a drop ten times as great. Now the old sea bed is not a hated desert to be gratefully blotted out by a new sea but a rich agricultural empire worth a hundred millions of dollars and providing homes for 50,000 people. It is one of the ironies of nature that the Colorado River drove man from the Salton Basin a thousand years ago by turning to the Gulf while to-day it would drive him out by returning to the Salton Basin. For all these years the river has been flowing into the south it has been forcing back the head of the Gulf, building up the country, flattening out its grade, and the cycle seems almost completed. The Colorado River is ready to turn again into the Salton Basin and blot out the civilization of to-day as it blotted

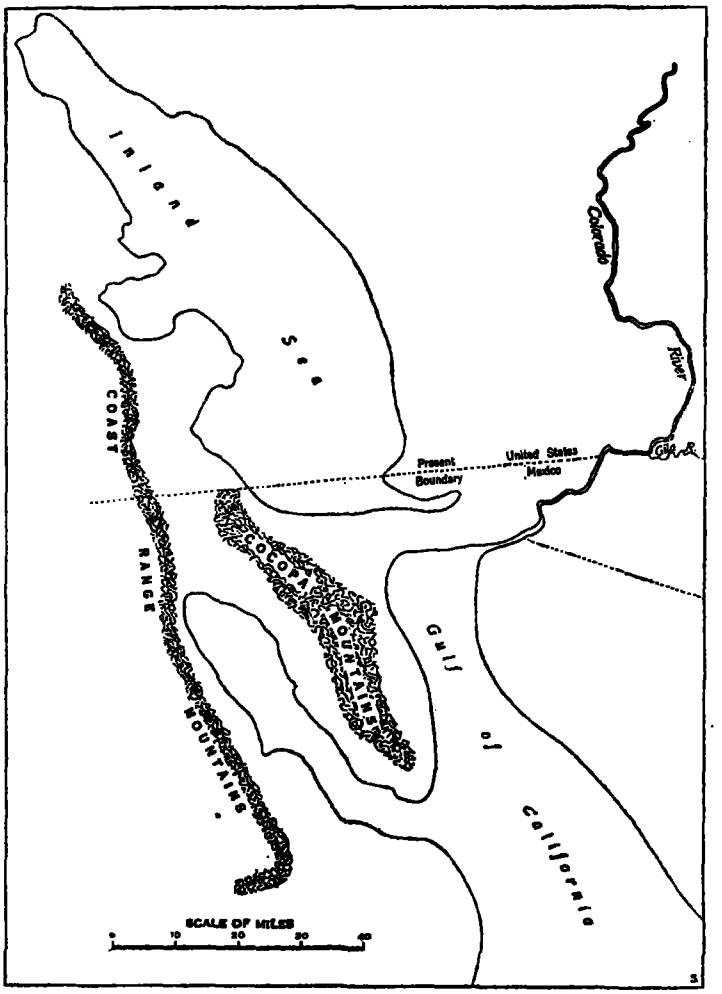

FIG. 2.—Later changes in the Gulf of California and adjacent country. (See fig. 1.)

out the desert of yesterday. This is *the* great problem of the lower Colorado, the problem of a river tremendously powerful during its annual flood period ready with

FIG. 4.—A sand-hill area 5 miles wide and 40 miles long marks the eastern boundary of the Salton Sink

FIG. 5.—Trying to check the break of 1905. It was finally closed at a cost of over $2,000,000

FIG. 6.—During the break of 1905–6 the New and Alamo Rivers cut back from north toward the Colorado ,forming channels 50 to 60 feet deep

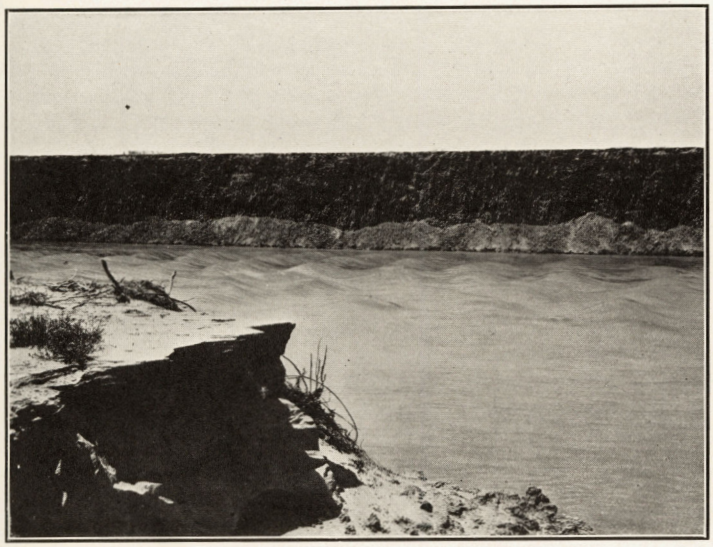

FIG. 7.—West bank of the New River Canyon, 4½ miles west of Brawley, Calif., August 30, 1906. This canyon was created by the break of 1905–6 and is nearly 70 miles long

FIG. 8.—Headgates of the Imperial Canal through which some 3,593,000,000 gallons of water flow daily

the preparation of a thousand years to turn its flow back into the old sea bed.

In former times man was powerless before the river; now with the weapons of our modern civilization at his hand man is no mean adversary even for the mighty Colorado. In 1905 the river tore away the intake of the Imperial Irrigation Co. Canal and sent its whole flow into Salton Sink. After 16 months of effort the break was closed at a cost of over $2,000,000 and the river again flowed south. (Figs. 5 and 6.) In 1909 the Colorado again turned west following the old channel of Bee River to Volcano Lake. Early in 1911 a levee was completed blocking the Bee channel, money for the work having been provided by the Congress of the United States, but high water a few months later tore away this levee and the river again flowed into Volcano Lake.

The defenders dropped back to this new line and built up a strong system of defense. Experience had convinced engineers of the futility of opposing the river with dirt levees and rock revetment was used as far as practicable. The defenses, reinforced every year, held well but the river flowing into the Volcano Lake basin dropped much of its load, filled in the bed of the lake and year by year raised the plane of attack. In 1921 the assault was so fierce that the flood waters lapped the ties of the railroad along the levee crest. It is said that only a shift of wind that drove the waters back a little saved the day. At least the levees held. But the line was too dangerous. A break in the Volcano Lake defenses would send the river into the channel of the New River, already deep scoured by the break of 1905 (fig. 7.)

During the low water period which followed a flank attack was made on the Colorado. At a favorable point 8 miles east of Volcano Lake a cut 4 miles long was dredged in the south bank, piercing the broad crest of the delta cone and reaching lower land. A strong rock fill dam was thrown across the old channel forcing the river into the new. This area south of the river was normally flooded by overflow at high water and a drainage system had developed known as the Pescadero River. It was hoped that the Colorado would take one of the tributaries of the Pescadero, scour it out and make a good channel through from the cut to the Hardy Colorado. This new channel would shorten the distance to the Gulf by several miles, offer a somewhat better grade than the old course and, it was expected, relieve the strain on the north bank for a number of years.

The high waters of 1922 and 1923 were carried successfully but the hoped-for channel had not been made. Instead the river, following its old custom has spread out, lost velocity and is building up a delta at the southern end of the cut. In 1923 gage readings above the cut were a foot higher than for the same discharge in 1922. Levees, discarded for new lines, which held the river in 1922 were overtopped in 1923. This is a brief history of the problem to date. There has been no break into the Salton Basin since 1906 but at every high water there is threat of one. On the holding of a long, thin line of granite-faced levees depends the safety of the Salton Basin country.

A break would be a very serious matter. That of 1905 cut a network of channels which converged into the New and Alamo Rivers. The channels of these rivers scoured back from the north to a depth of from 50 to 60 feet, the New River to near Volcano Lake and the Alamo to near the international boundary. A new break if it cut one of these channels back to the main river would offer a tremendous problem. The cut if long unchecked would work back up the river for miles dropping the river level many feet, quite possibly threatening the security of Laguna Dam. To turn the flow south again the river would have to be dammed and lifted up out of this deep channel. In a land of bottomless silt dam building under the most favorable circumstances is not easy. Even supposing the break stopped our problem is not solved. The deep cut channels of one break only make the threat of another more menacing. So the matter stands. The river is bringing down its 6,000,000 carloads of silt and sand a year, a hundred thousand acre-feet of damming material. During the last year engineers, to balance this, threw in 6,000 carloads of rock to keep their lines safe. The problem is being met and met bravely but it is not solved. Each year the threat of diasaster is renewed.

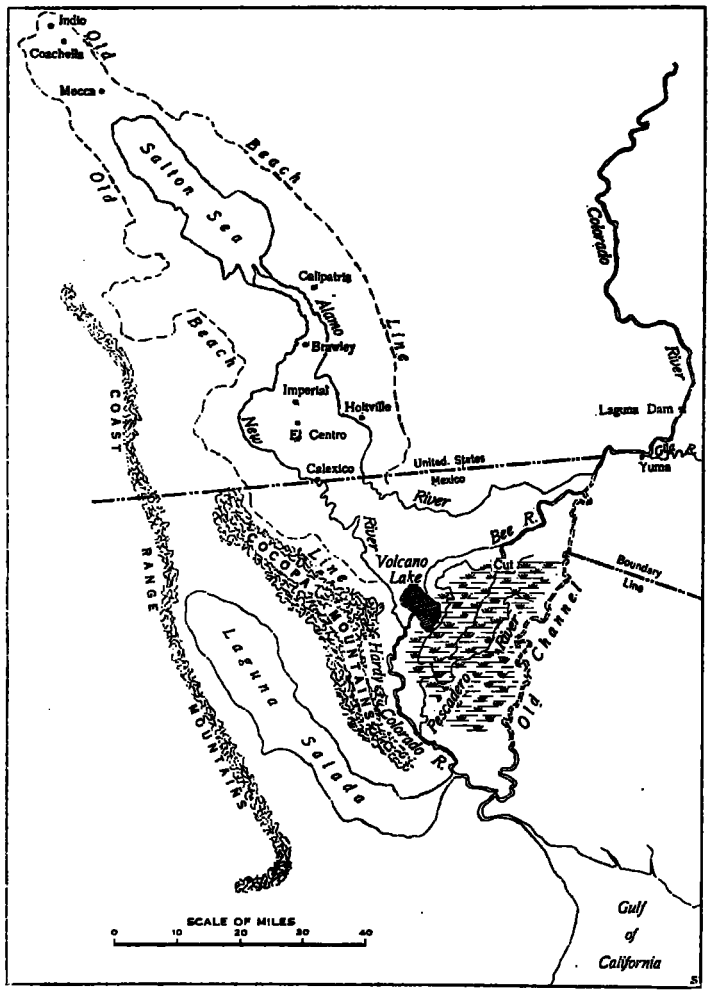

FIG. 3.—Gulf of California and adjacent country to-day. (See figs. 1 and 2.)

This is our chief problem of the lower Colorado. Others are secondary. This is a problem of floods. Oddly enough one of the others is lack of enough water. Three months after we have seen the millions of acre-feet of water go tearing by to the Gulf, utter waste, the Colorado has ceased to be a big river. Quite a number of times in the last 20 years it has become so small a stream that the entire flow reaching the Imperial Canal (fig. 8) intake fell below present irrigation demands. Safe development of the country is limited by the minimum flow of the river. Construction of the all-American Canal is held not justified under this limitation.

The Gila River is our third problem. The floods of the Colorado come at a definite time each year. Every year the organization is ready—men, cars, locomotives,

steam shovels, supplies. As the river rises slowly any weak point in the defences is noted and reinforcement rushed in. The Gila on the contrary is a flashy stream. A big, general rain over Arizona, especially if it finds snow to melt, will start a flood overnight. In January, 1916, the flow of the Gila, entering the Colorado just above Yuma, increased from 1,300 second-feet to nearly 200,000 second-feet in five days. There is little time to prepare for such a flood, to build up an organization to fight it. Dangerously high stages in the Gila have occurred but three times in the last 20 years. Fortunately the river drops almost as fast as it rises. A break in the levees may cause damage but it can be soon mended. Where the Colorado floods are formidable for weeks, the Gila floods are measured in days.

These problems can be solved. In the great canyon of the Colorado which crosses northern Arizona there are a number of favorable sites where a dam could impound a whole year's flow of the river. It is estimated that the power development alone would pay for such a dam. At present there are many matters in dispute over the building, questions as to best location, as to water and power control, as to State rights and national rights, as to Government or private construction. But these questions can be settled and the dam will be built, and with its building will pass the problem of floods and low water in the lower Colorado River. A river shorn of its floods will cease to be a menace to development; a river with even flow throughout the year will not only provide abundantly for the needs of present irrigated areas, but will permit the development of acreage three or four times as great. The problem of the Gila is being solved gradually. Construction of the Roosevelt Dam was the first step, another dam in the Salt River and two in the Verde already provided for will help as much again. By the time the great Colorado Dam is built it is probable that the Gila will be largely shorn of its power, also, and these problems of the lower Colorado will cease to be. It is part of the passing of the old West and the coming of the new.

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TIDAL BORE AT MOUTH OF COLORADO RIVER DECEMBER 8 TO 10, 1923

By JAMES H. GORDON

[Weather Bureau, Yuma, Ariz., December 1923]

The lower delta country, as observed on this trip, is a great level plain so flat that the elevation probably did not vary a foot in the 25 miles crossed. The ruts which formed the road furnished the greatest variation in elevation observed. The plain is almost entirely destitute of plant growth. A liberal estimate would be one small bush to every hundred acres. There was a strong wind blowing. My hat went off. One of the men sprang after it, but was distanced. Because of recent rains it was unsafe to leave the road and follow "cross country." We did not follow the road which trended southeast while the hat went straight south. The hat was kept in sight for more than 3 miles and in that distance there had not been so much as a bush to check it in its mad flight. This to illustrate the character of the country. There are no recognizable channels across it except occasional drainage lines a few inches deep. Water from the Colorado at flood times and from overflow tides must cross this plain to reach Laguna Salada, which they are supposed to feed. The elevation of the plain is given as 8 feet at the northern end and 7 a little distance south of La Bomba.

While crossing this open country Pinto Mountain was observed. It is an isolated peak 1,500 to 1,800 feet high, rising abruptly from the western edge of the plain just south of the entrance to Laguna Salada. It is normally dark in color with its steep slopes grotesquely spotted with big patches of sand, some probably fully an acre in extent. Apparently the high north winds blowing down the Laguna Salada Valley pick up nearly their maximum load of sand. Eddies and swirls on the lee side of the mountain check the wind velocity enough to cause a dropping of the sand load. Time did not permit a close study of the mountain.

About 3 miles from La Bomba the road ran into water. It was shallow but extensive, so we left the cars and waded. The water was nowhere more than 6 inches deep, underlaid with a very adhesive mud, and covered perhaps half of the distance. A few "islands" were fairly dry. The rest of the way was mud. The water came from a tidal overflow of two nights previous and would require, we were told, two more days to drain off.

The "city" of La Bomba, the "seaport" of this section of Mexico with two small steamers a week, consists of seven small buildings, including a radio station, and at the time of our visit boasted five inhabitants and seven automobiles and trucks. The "port" is a slushy, crumbling river bank. I did not witness the method of unloading freight but with a normal tidal range of fully 12 feet, strong river and tidal currents and only a crumbling mud bank to work from it must present many difficulties. The freight brought in is mostly liquor for the border towns while fish are shipped south. The "city" is flooded about 6 inches deep every new moon, we were told, and at times of high water in the river it is cut off for weeks at a time. It is soon to be linked with Maxicali by Government-built railroad, much of the grading has been done, but it can never be much of a port. At present it seems to be the only point which may be reached by automobile from which the bore may be observed.

We reached La Bomba at 11.30 a. m. December 9. A strong, cold north wind was blowing and having taken the lay of the land, measured the height of the bank and set stakes by which to judge the bore we took shelter in the lee of one of the houses. A mountain chain of many interlocking ranges lies some 8 miles to the west and was remarkably impressive and beautiful in the sandstorm haze. From our shelter it was possible to see some distance down the river.

The coming of the bore was first called to our attention by the disturbance among a big flock of white pelicans fully 6 miles away. Fish always follow the bore in, we were told. The brown line of the bore itself was visible with the glass at perhaps 3 miles. Its speed appeared to be nearly 8 miles an hour. As a spectacle it was disappointing. This was doubtless due in some measure to the strong north wind that had been fighting the tide all the way up the Gulf. Up to the moment that the bore, or first wave, arrived the current was running strongly seaward. In an instant it was reversed and racing up the river. The bore was not over 3 feet high, a racing wave fully a mile long, foam crested and perhaps a foot higher over the shallows and sand bars. In deep water it was like a ground swell apparently running *over* the outgoing tide and river current. The *lack of turmoil between the two opposite currents was surprising.* The level of the river rose 3 feet in the first minute and 5 feet in 15 minutes. The bank was 15 feet high at low tide. The high tide of two nights previous had filled the channel and overflowed the surrounding country 6 inches